

The Development of Inflatable Array Antenna

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JPL/NASA's deep-space exploration has been placing emphasis on reducing the mass and stowage volume of its spacecraft's high-gain and large aperture antennas. To achieve these goals, the concept of the inflatable planar array antenna was recently introduced at JPL. Because the planar array's flat aperture is a "natural" surface, its required surface tolerance is much easier to maintain via the inflatable structure than that for a specifically curved surface such as a parabola. In addition, a planar array offers the possibility of wide-angle electronic beam scanning. Certainly, to realize this inflatable array antenna technology, several technical challenges remain to be resolved. In the RF area, it is essential to mitigate the array's weaknesses of narrow bandwidth and poor efficiency. In the mechanical area, the development of the inflatable structure rigidization technique, controlled deployment technique, and the structure dynamic analysis technique are necessary.

Three inflatable array antennas that were developed recently are a 3.3m x 1.0m L-band synthetic aperture radar (SAR) array for Earth remote sensing application, a 1.0m-diameter X-band reflectarray and a 3m-diameter Ka-band reflectarray both for deep-space telecom application. The L-band SAR array is a 1/3 size technology demonstration model of the future full-size (10m x 3m) array. It consists of a rectangular frame with an inflatable tube that supports and tensions a three-layer thin-membrane radiating surface with microstrip patches, ground plane, and microstrip power division lines. The measured results show that the antenna has achieved the required bandwidth of 80 MHz at the center frequency of 1.25 GHz and a peak gain of 26.7 dB with an aperture efficiency of 74%. The antenna has a total mass of 15 kg with an average of 4.3 kg/m², which includes the inflation system and its container. It is projected that the full-size array would achieve an average mass of 2 kg/m². The membrane surface achieved the required global flatness of less than ± 1 cm and local flatness of ± 0.75 mm. The second inflatable array antenna is an X-band reflectarray, which has an inflated toroidal tube that supports and tensions a 1.0m diameter two-layer-membrane reflectarray surface. The top layer has many isolated microstrip patches and is separated 1.3 mm from the bottom ground plane layer. A set of inflated tripod tubes is attached to the torus as struts to support the feed horn. The same tube and thin-membrane materials are used here as those described above for the SAR array. This inflatable antenna structure achieved a mass of 1.2 kg (excluding the inflation system). The antenna provided a good radiation pattern with both peak sidelobe and peak cross-pol levels below -18 dB. The overall antenna efficiency was measured to be 37%, which could be improved in the future to become higher than 50%. The third antenna is an inflatable 3m Ka-band reflectarray, which has structural form very similar to that of the second antenna and has achieved the required surface flatness. Its detailed performance results will be given during the presentation. The performance of all three above antennas have proven that the inflatable array antenna technology is now realizable.

DESCANSO Symposium

The Development of Inflatable Array Antennas

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The Development of Inflatable Array Antennas

JPL's two major functions:

- Deep space exploration**
- Earth remote sensing**

General antenna requirements:

- High-gain and large-aperture**
- Low mass**
- Small launch-vehicle stowage volume**
- Low mission cost**

The Development of Inflatable Array Antennas

First Solution: Inflatable parabolic reflector

Program: NASA IN-STEP program

Inflatable Antenna Experiment (IAE)

A 14m dia. Inflatable parabolic reflector was flown on the space shuttle Endeavor in May 1996

Successful deployment, but poor surface tolerance

The Development of Inflatable Array Antennas

**Alternate solution: Inflatable / thin-membrane
flat array antennas**

Reasons:

- 1. Much easier and more reliable to maintain
a flat “natural” surface than a curved
parabola**
- 2. Possible to achieve wide beam scanning**

Disadvantage: Small bandwidth

The Development of Inflatable Array Antennas

Four inflatable / thin-membrane array antennas,
recent breadboard developments:

- **3.3m x 1.0m inflatable L-band SAR array**
- **1m dia. inflatable X-band reflectarray**
- **3m dia. Inflatable Ka-band reflectarray**
- **Frame-supported thin-membrane array**

Inflatable L-Band Microstrip SAR Array

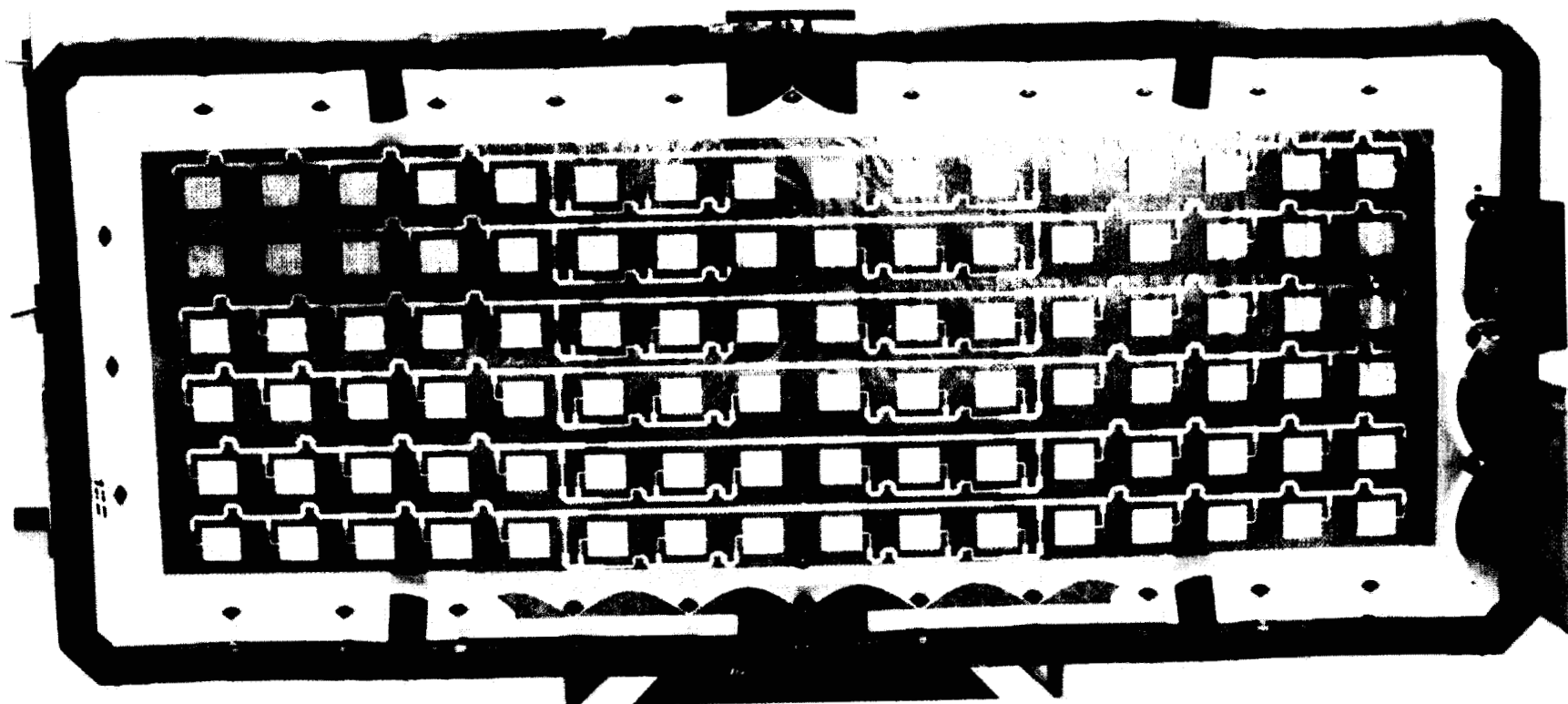
Requirements

- **Frequency: 1.25 GHz**
- **Bandwidth: 80 MHz**
- **Polarization: dual linear**
- **Sidelobe level: -13 dB**
- **Cross-pol level: -20 dB**
- **Efficiency: >50%**
- **Aperture size: 3.3m x 1.0m**
- **Mass: < 3 kg/m²**
- **Surface flatness: 1 cm global; 0.08 cm local**

RMS?

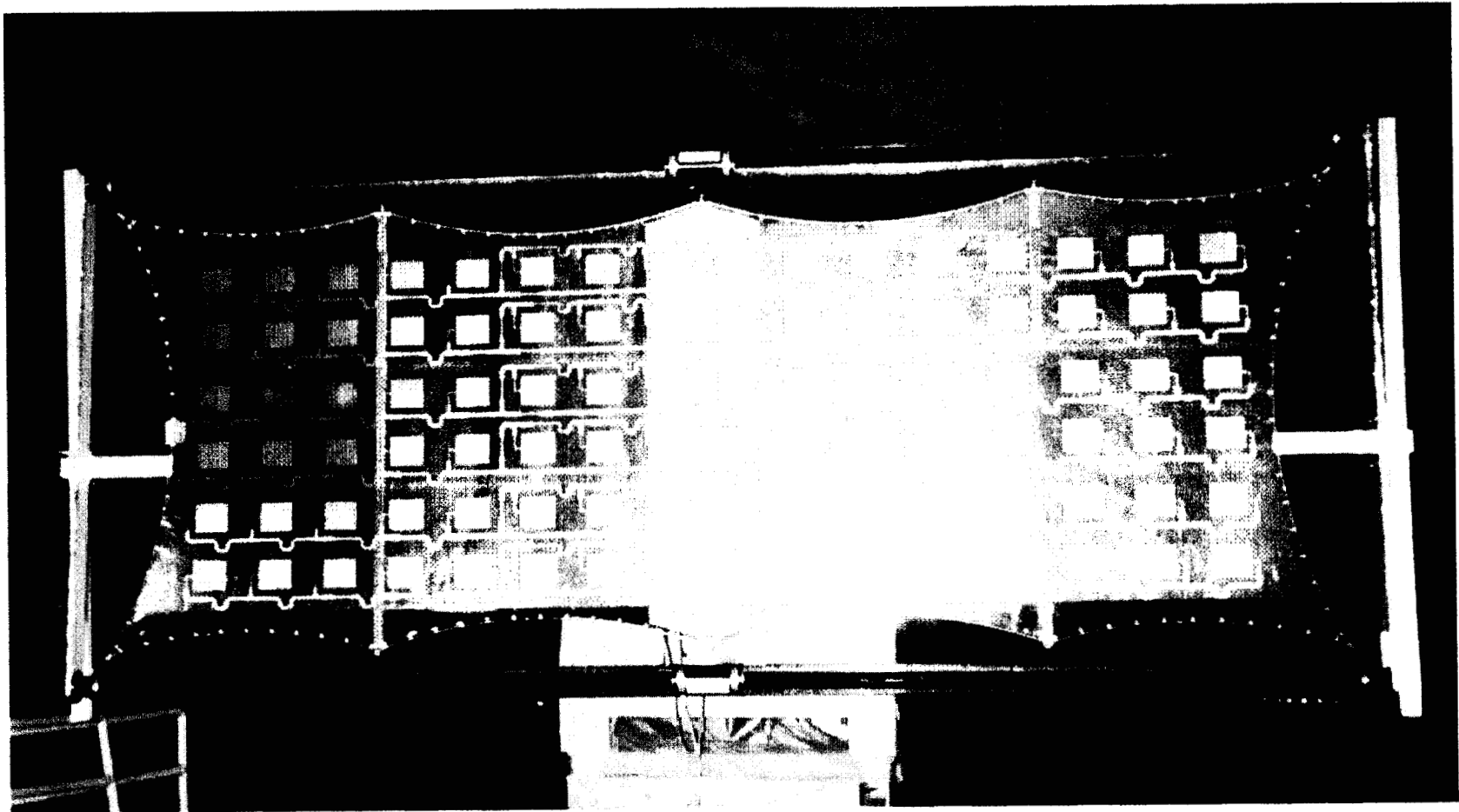
Inflatable L-Band SAR Array

(by JPL/ILC Dover, Inc.)

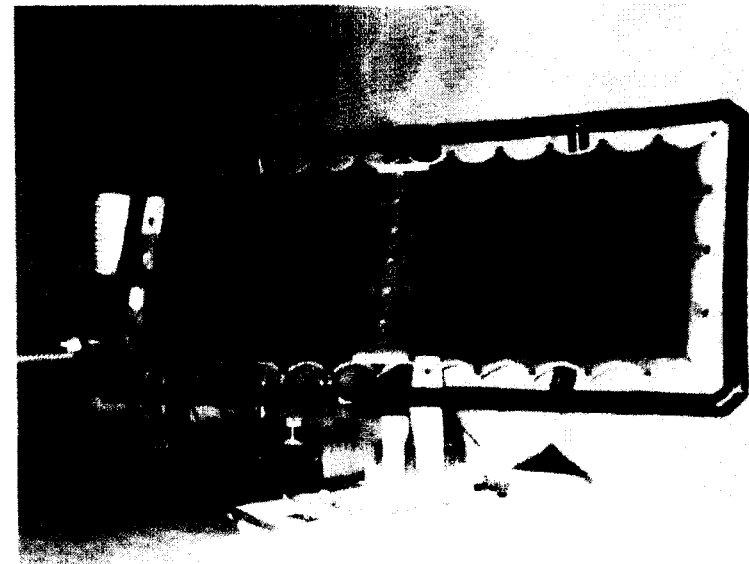
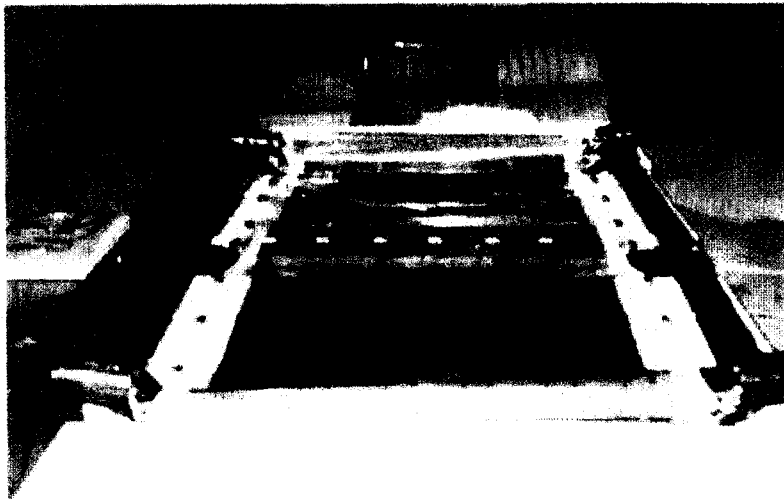
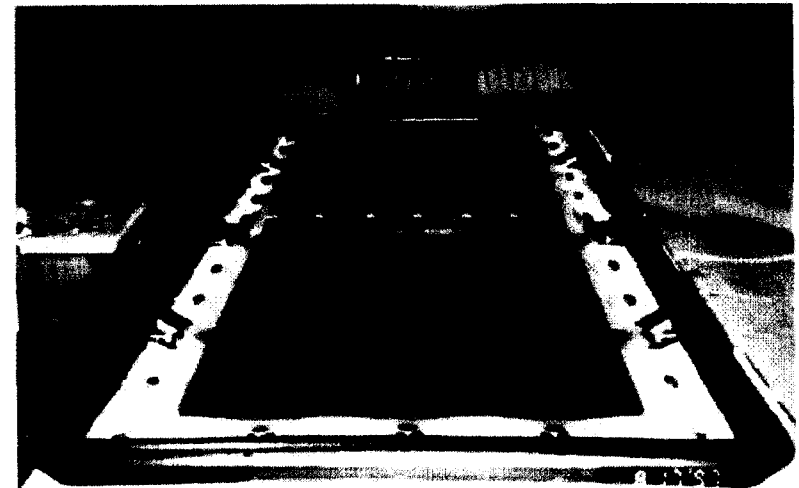
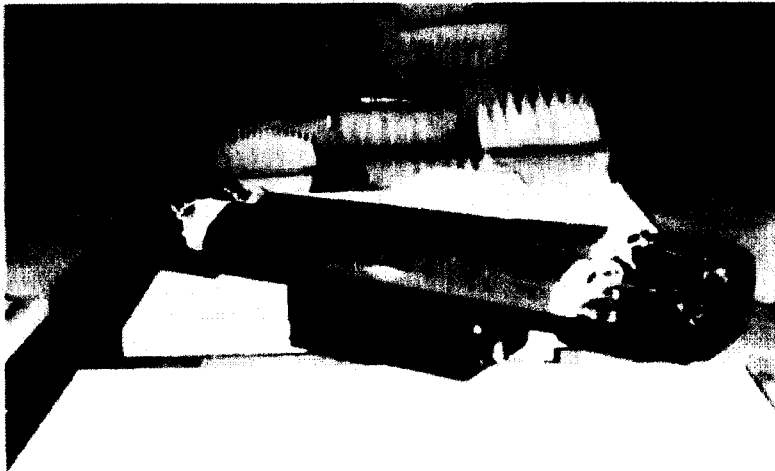


Inflatable L-Band SAR Array

(by JPL/L'Garde Corp.)

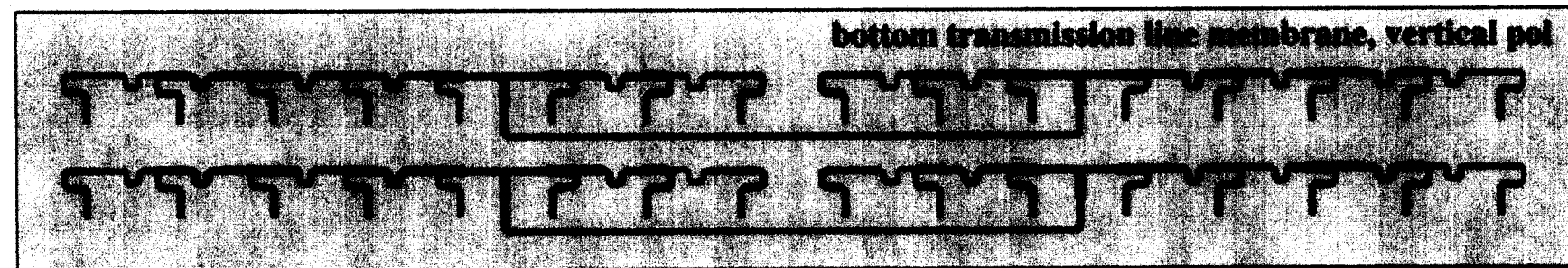
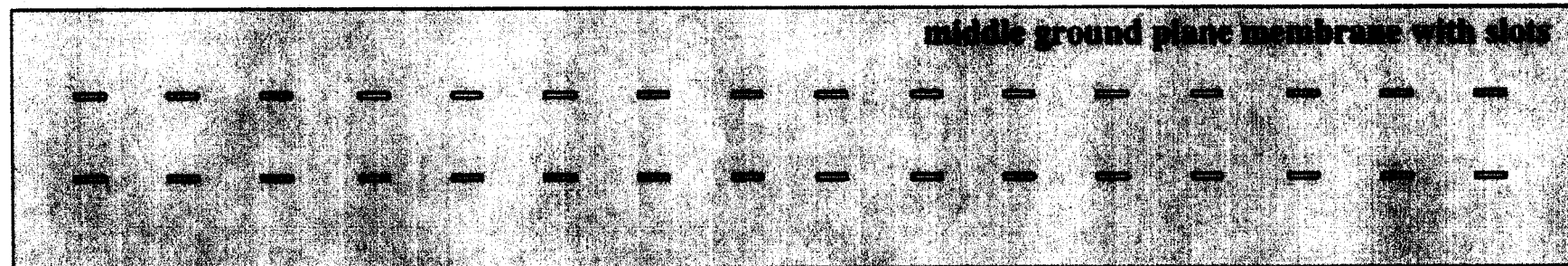
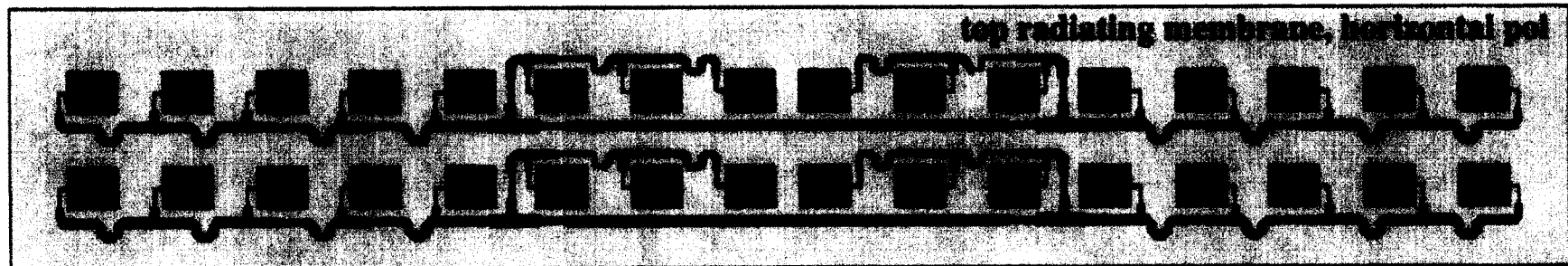


Inflatable SAR Array antenna



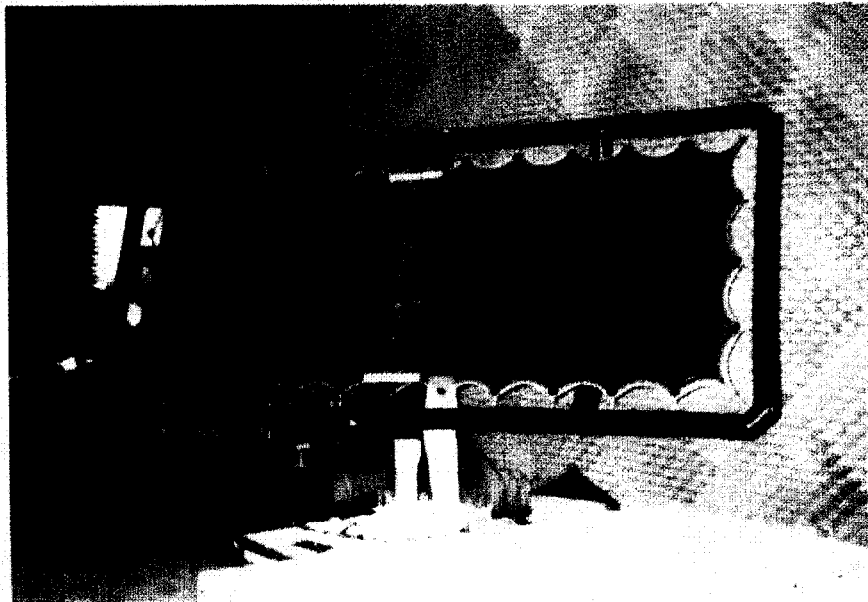
Inflatable Microstrip SAR Array

Dual-Pol Aperture Coupled 3 Membrane-Layers





Inflatable SAR Array Antenna



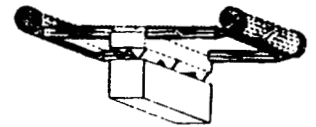
CHARACTERISTICS:

- frequency: L-band (1.25 GHz)
- bandwidth: 80 MHz
- size: 3.3 m x 1 m aperture
- mass: 15.3 Kg
- polarization: dual linear
- peak gain: 25.2 dB
- efficiency: 52%
- surface flatness: $\leq \pm 0.075$ cm
- material: kevlar tube/kapton membrane



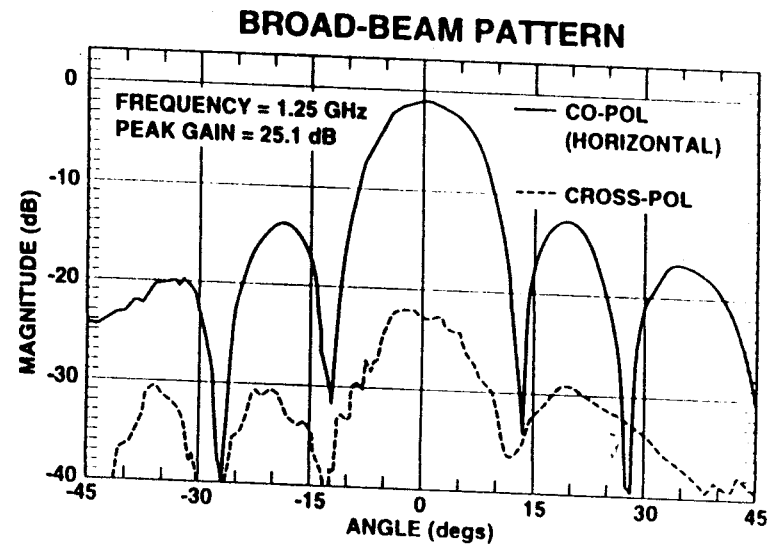
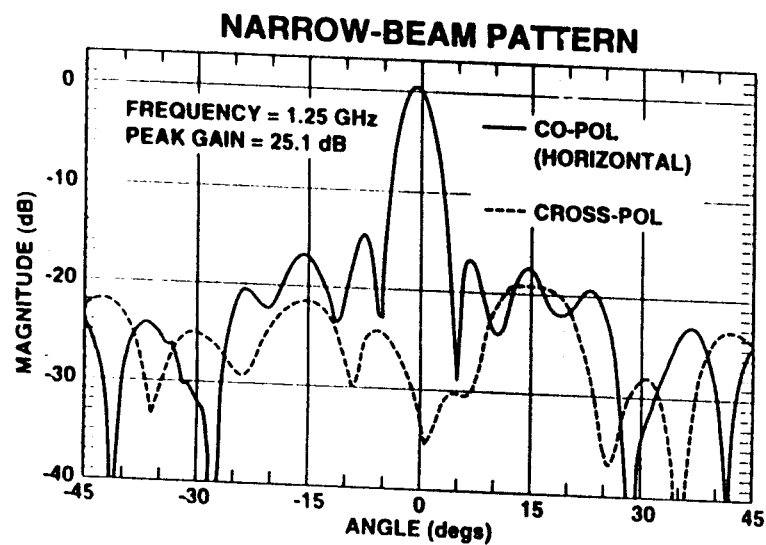
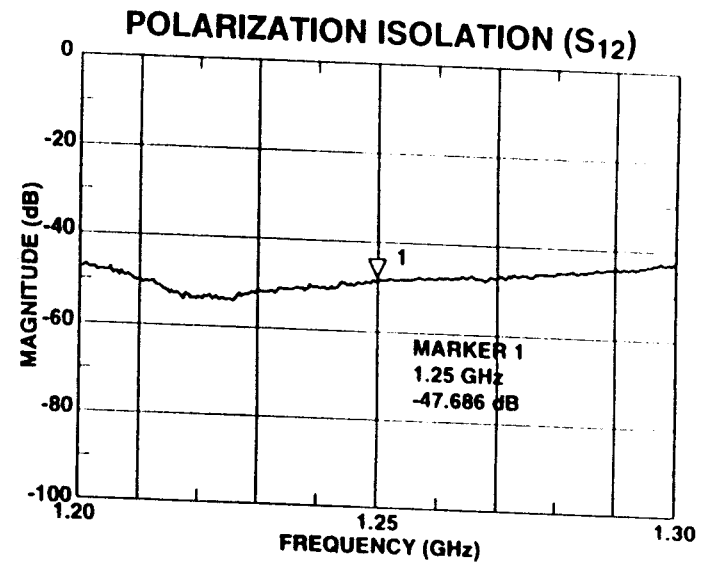
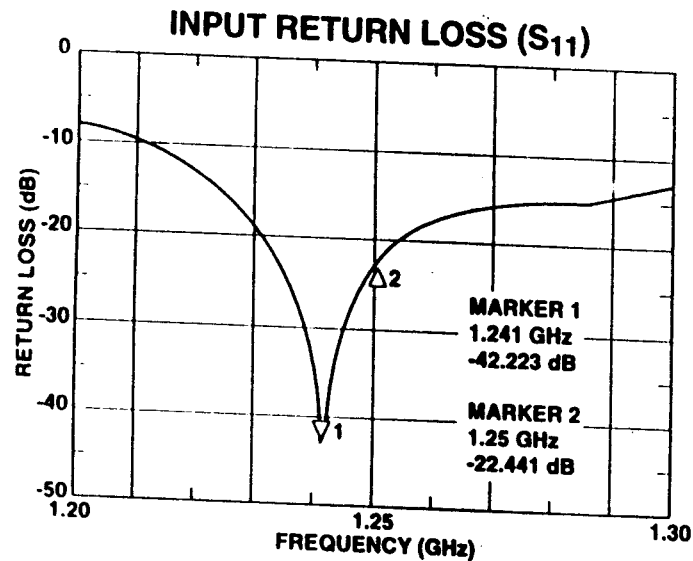
INFLATABLE SAR ARRAY RF DESIGN

- PRINTED MICROSTRIP PATCH ARRAY WITH AIR SUBSTRATE USING THIN MEMBRANES, TOP 2 MEMBRANES SPACING = 0.5", BOTTOM 2 MEMBRANES SPACING = 0.25"
- THIN MEMBRANE HAS 5-MICRON COPPER ON 2-MIL KAPTON® (5-MICRON COPPER \Rightarrow 2 SKIN DEPTH AT L-BAND)
- MICROSTRIP POWER DIVIDER LINES USE PARALLEL/SERIES COMBINATION: PARALLEL TO ACHIEVE BANDWIDTH, SERIES TO MINIMIZE ^{OCCUPIED} NEEDED REAL ESTATE
- 3 MEMBRANE LAYERS:
 - top layer has radiating patches and horizontal-pol power divider lines
 - middle layer is ground plane with aperture coupling slots
 - bottom layer has vertical-pol power divider lines
- CENTRAL FEED PROBES ALLOW CONNECTION TO T/R MODULES AND PHASE SHIFTERS FOR ELECTRONIC BEAM SCANNING IN ONE DIMENSION



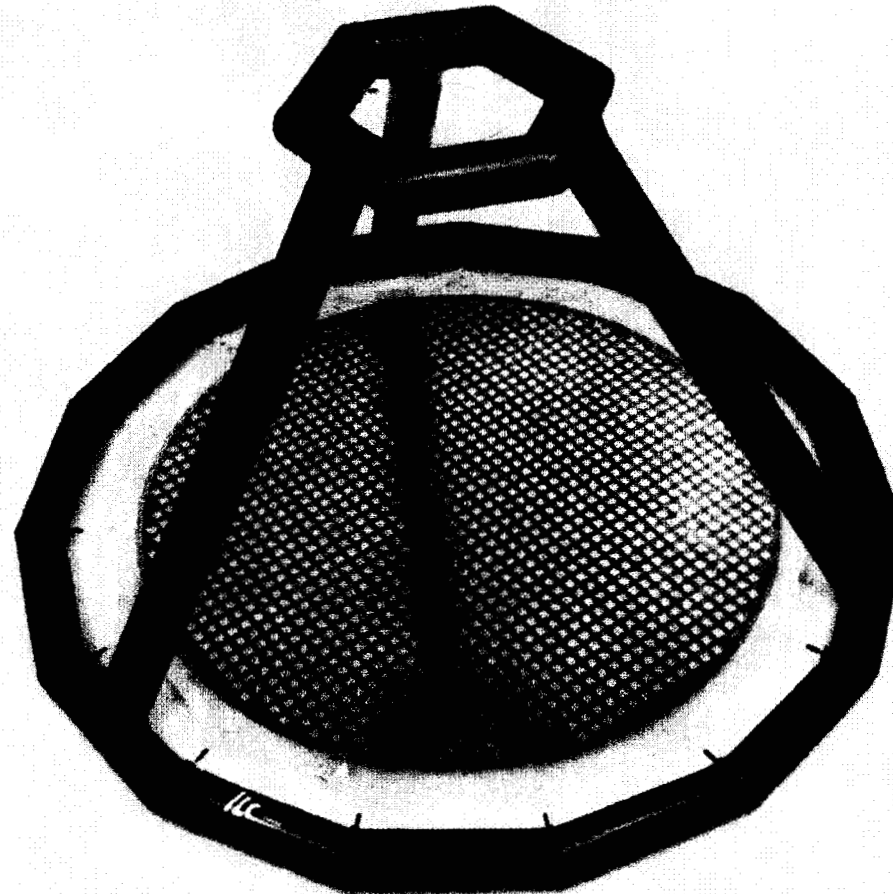
INFLATABLE SAR ARRAY ANTENNA

RF TEST RESULTS



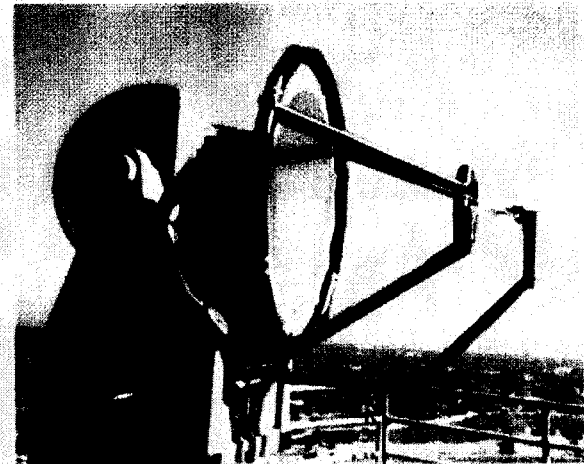
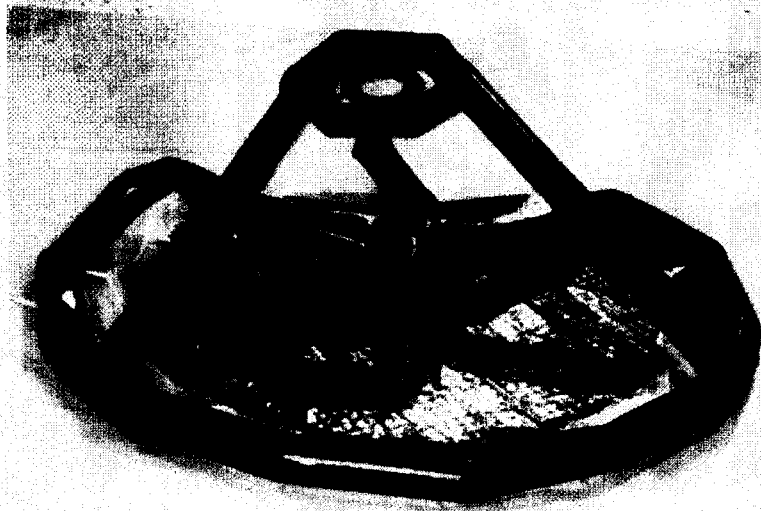
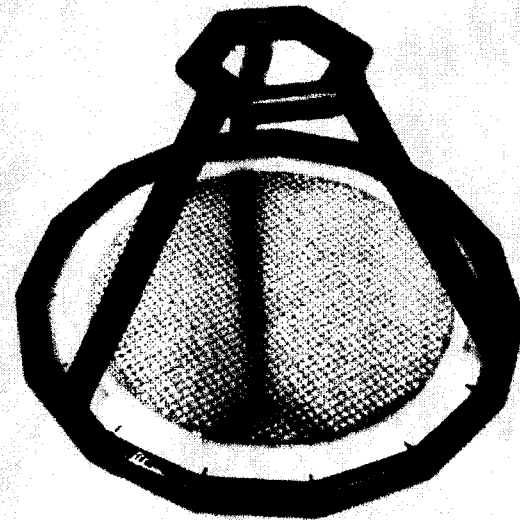
Inflatable X-Band 1m Reflectarray

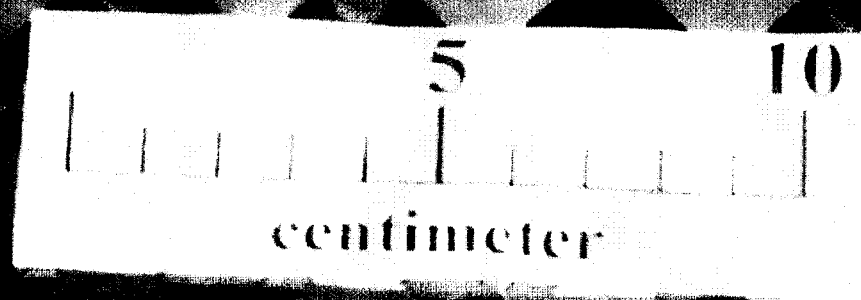
(by JPL/ILC Dover, inc.)



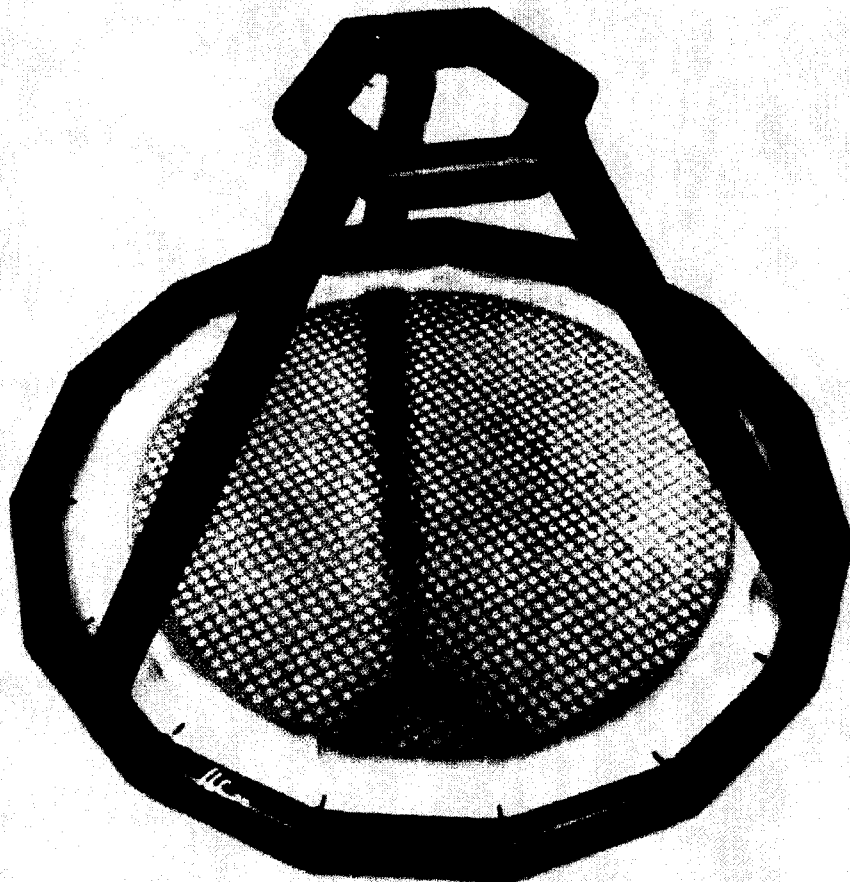
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JPL 1 m X-Band Inflatable Microstrip Reflectarray





JPL 1 m X-Band Inflatable Microstrip Reflectarray



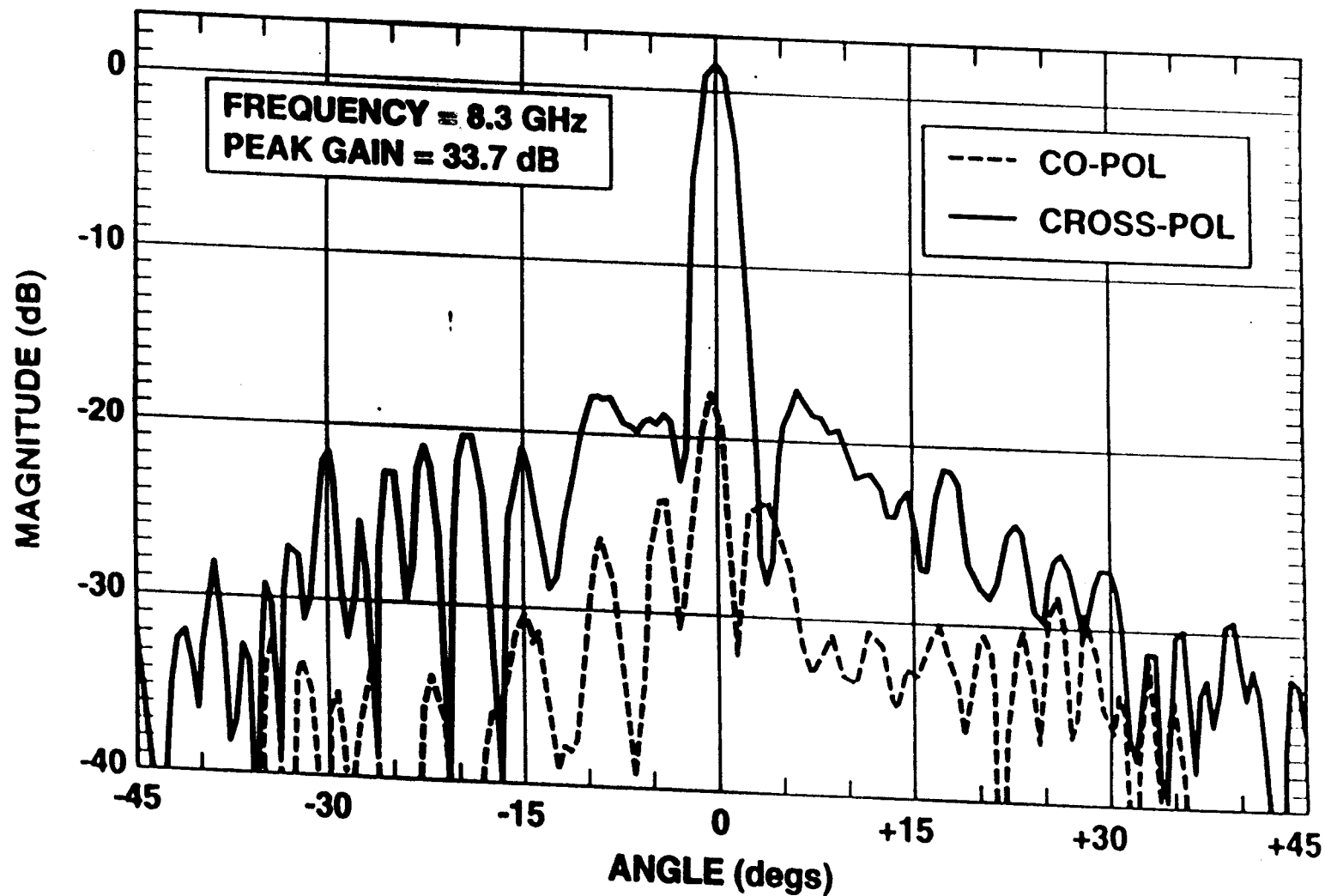
CHARACTERISTICS:

- **mass: 1.2 Kg**
- **3dB beamwidth: 2.4°**
- **peak gain: 33.7 dB**
- **efficiency: 37% (room for improvement)**
- **polarization: circular**
- **surface flatness: $\leq \pm 0.075$ cm**
- **Material: kevlar tube/kapton membrane**

ADVANTAGE:

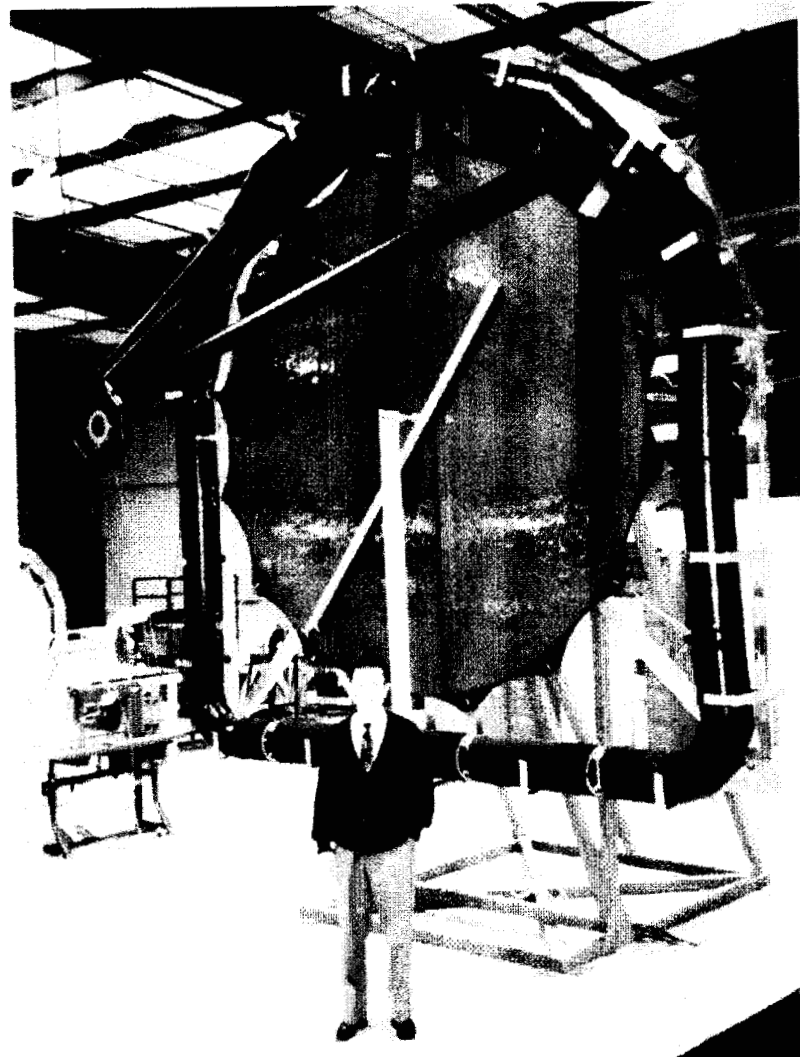
**easier and more reliable to maintain
surface flatness than inflatable parabola**

Measured pattern of the 1-meter circularly polarized
inflatable microstrip reflectarray antenna



Inflatable Ka-Band 3m Reflectarray

(by JPL/ILC Dover, Inc.)



Inflatable Ka-Band 3m Reflectarray

Deployment Sequence

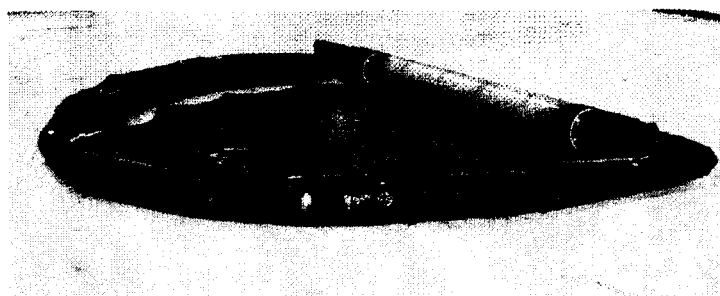
Deployment Sequence Pictorial Summary



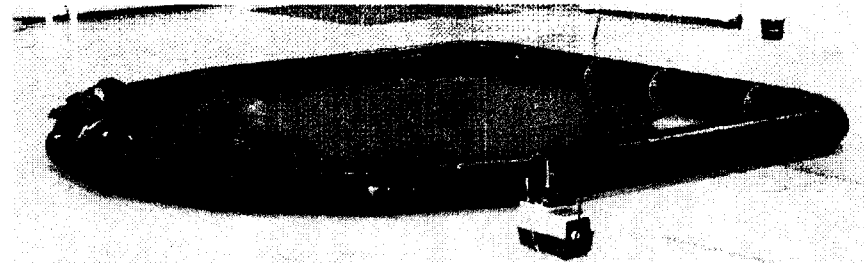
↑ Packed State



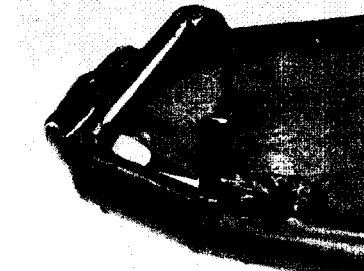
↑ Center chamber of the frame begins to inflate



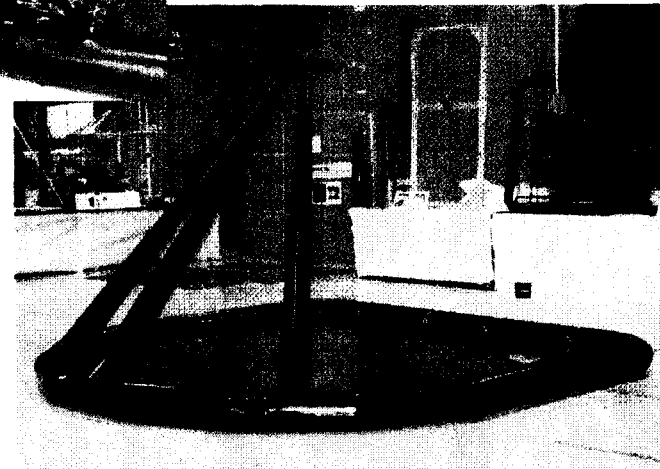
↑ Straight sections of the frame is mid-way through deployment



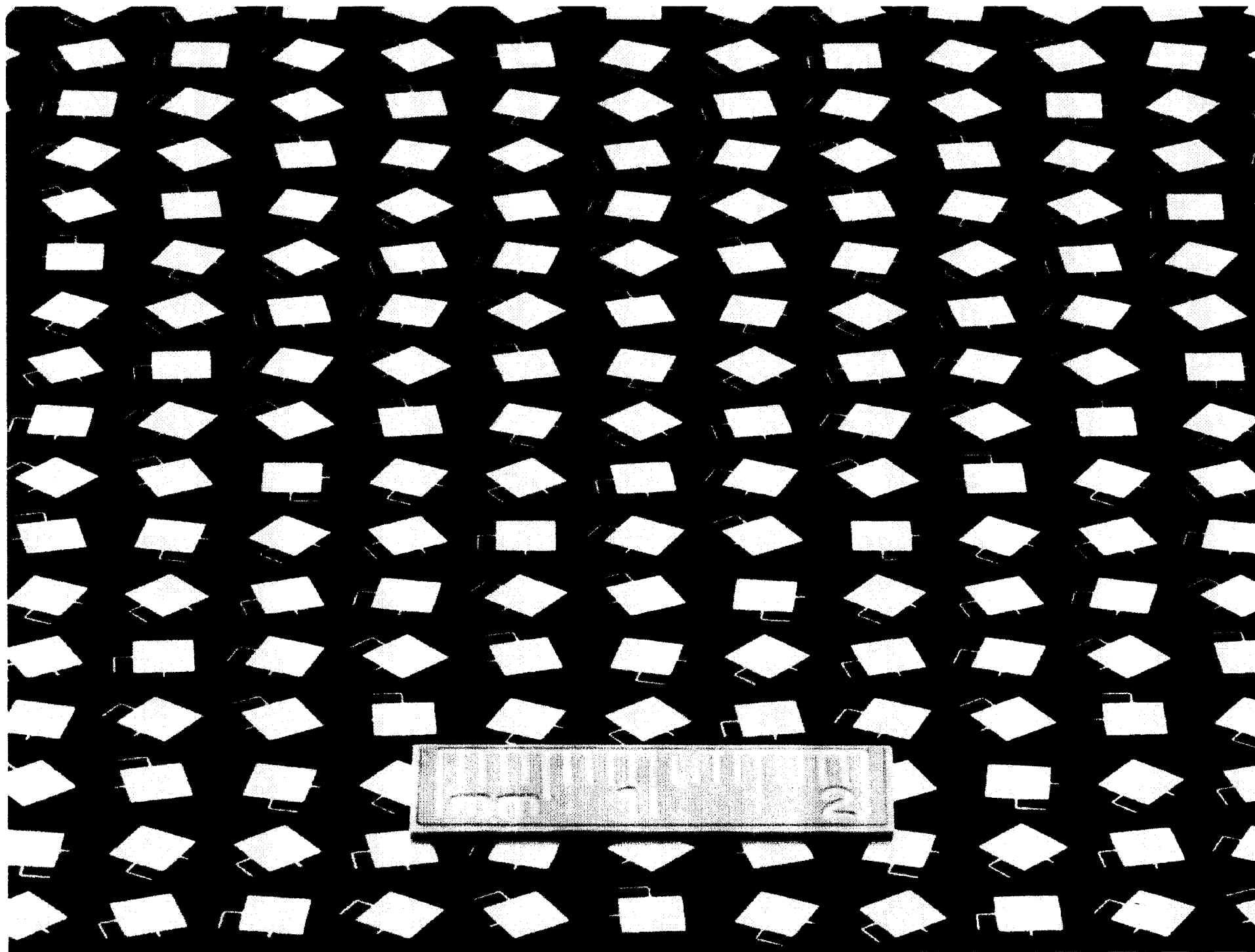
↑ Horseshoe frame fully inflated



⇌ Center Column begins to deploy

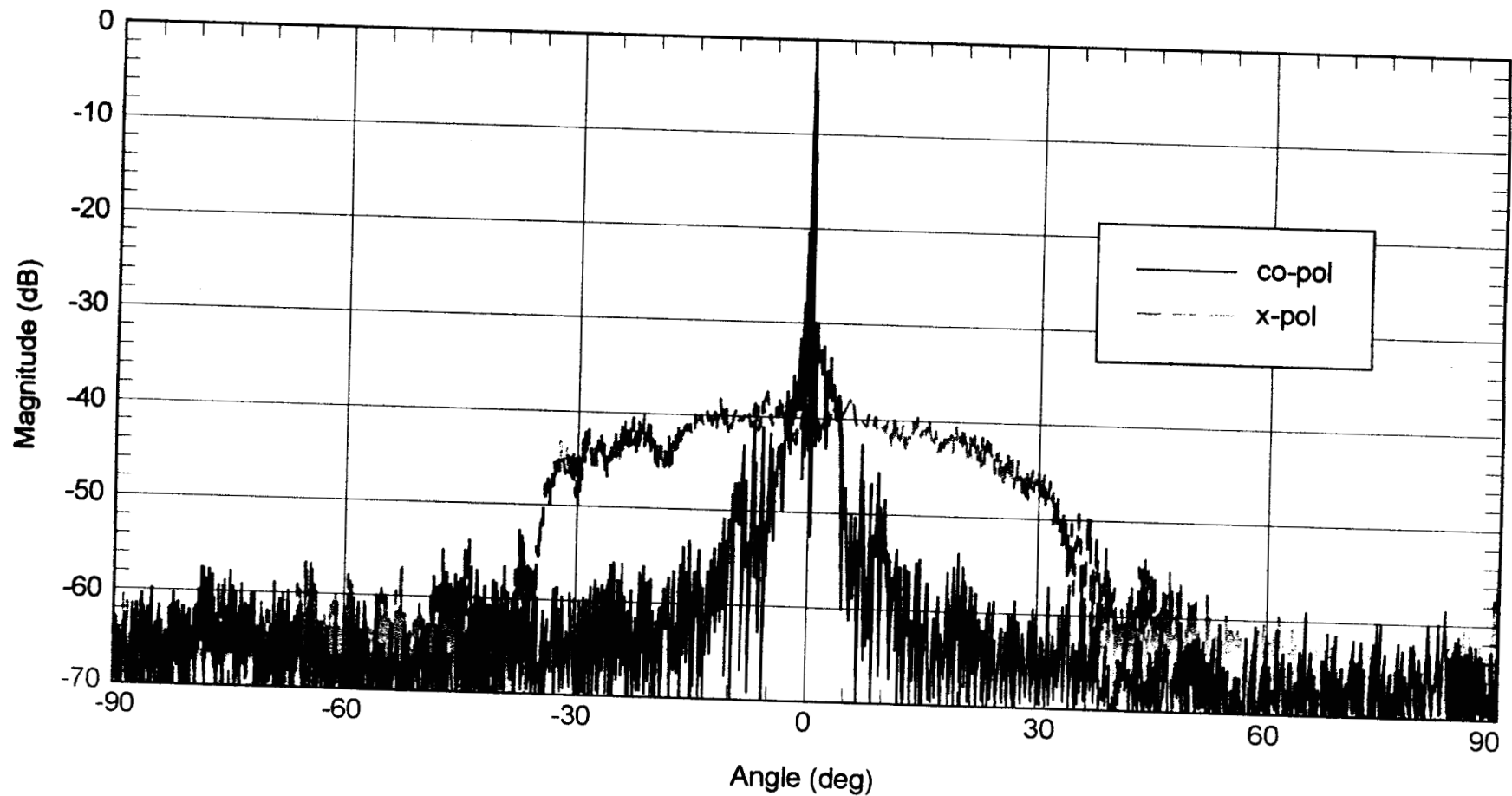


↑ Fully deployed



Measured Radiation patterns

3m Ka-Band Inflatable Reflectarray



The Development of Inflatable Array Antennas

3m Ka-Band Inflatable Reflectarray Breadboard Test Results

	GOAL	TEST RESULTS	COMMENTS
Average Mass (kg/m²)	1.0	1.8	Reasonable mass Density = 2 kg/m²
Total mass (kg)	7.0	12.8	
Stowage volume	small	3.5m x 0.45m cylinder	Can be fitted in many Launch vehicles
Surface flatness	0.5 mm RMS 0.8 mm peak	0.1 mm RMS 0.3 mm peak	
Efficiency	45%	10%	Caused by RF design Flaw, started 2nd iteration
Sidelobe level	-25 dB	One lobe at -18 dB Most -30 dB	good
Cross-pol level	-25 dB	One lobe at -27 dB Most -40 dB	excellent

The Development of Inflatable Array Antennas

Design/Modeling Tools and Techniques

- **EnsembleTM** (Integral Equation / Moment Method)
- **Planar array theory** (for reflectarray)
- **Multi-mode cavity theory**
- **Valid concepts and array configurations**

The Development of Inflatable Array Antennas

Technical Challenges and Key Issues

- **Maintain required flatness, proper membrane separation, and accurate alignment of a multi-layer membrane structure**
- **Need in-space rigidization techniques (stretched aluminum, water-based gel, thermoplastic composite, etc.)**
- **Need controlled deployment mechanism**
- **Need membrane mountable T/R modules and components**
- **Reduce the size and mass of inflation system**
- **Develop accurate thermal and vibration stress analysis tools**